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Dual enhancing properties of LiF with varying positions inside organic light-emitting devices

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Abstract

A multilayer organic light-emitting device (OLED) has been fabricated with a thin (0.3 nm) lithium fluoride (LiF) layer inserted inside an electron transport layer (ETL), aluminum tris(8-hydroxyquinoline) (Alq_3). The LiF electron injection layer (EIL) has not been used at an Al/Alq_3 interface in the device on purpose to observe properties of LiF. The electron injection-limited OLED with the LiF layer inside 50 nm Alq_3 at a one forth, a half or a three forth position assures two different enhancing properties of LiF. When the LiF layer is positioned closer to the Al cathode, the injection-limited OLED shows enhanced injection by Al interdiffusion. The Al interdiffusion at least up to 12.5 nm inside Alq_3 rules out the possible insulating buffer model in a small molecule bottom-emission (BE) OLED with a thin, less than one nanometer, electron injection layer (EIL). If the position is further away from the Al cathode, the Al diffusion reaches the LiF layer no longer and the device shows the electroluminescence (EL) enhancement without an enhanced injection. The suggested mechanism of LiF EL efficiency enhancer is that the thin LiF layer induces carrier trap sites and the trapped charges alters the distribution of the field inside the OLED and, consequently, gives a better recombination of the device. By substituting the Alq_3 ETL region with copper phthalocyanine (CuPc), all of the electron injection from the cathode of Al/CuPc interface, the induced recombination at the Alq_3 emitting layer (EML) by the LiF EL efficiency enhancer, and the operating voltage reduction from high conductive CuPc can be achieved. The enhanced property reaches 100 mA/cm^2 of current density and 1000 cd/m^2 of luminance at 5 V with its turn-on slightly larger than 2 V. The enhanced device is as good as our previously reported non-injection limited LiF EIL device [Yeonjin Yi, Seong Jun Kang, Kwanghee Cho, Jong Mo Koo, Kyul Han, Kyongjin Park, Myungkeun Noh, Chung Nam Whang, Kwangho Jeong, Appl. Phys. Lett. 86 (2005) 213502].

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1. Introduction

Since the report of Tang and VanSlyke [1] with multilayer organic light-emitting devices (OLEDs), tremendous efforts have been made to improve the device performance. The Cambridge group [2] reported polymer light-emitting devices (PLEDs) and this had stimulated the synthesis research in the polymer field. To increase the OLED performances, carrier injection and transport mechanisms for both small molecular organic materials and polymers have been widely investigated. A modification at the interface between an organic material and an electrode increases the carrier injection into the organic material from the electrode, and one of the famous examples is the insertion of lithium fluoride (LiF) at the interface of an aluminum (Al) cathode and an organic electron transport layer (ETL). The role of the LiF electron injection layer (EIL) has long been in a dispute [3] since its introduction [4,5]. Its injection mechanism models are mainly categorized into two: one is the insulating buffer model [6] and the other is the interfacial chemistry model [7,8]. The insulating buffer model attributes LiF injection enhancement to its insulating property which takes more electric field when biased and hence allows tunneling injection with less barrier height. For the interfacial chemistry model, chemical reactions at the interface of LiF and Al layers or aluminum tris(8-hydroxyquinoline) (Alq_3), LiF and Al layers are the causes of the enhancement. The subsequent observed phenomena include the LiF dissociation [8], Alq_3 anion formation with Li doping [9], the surface potential reduction with the interface dipole [10], the protection of organic materials from the metal cathode [7], etc. A recent study by Jin et al. showed that the electron injection enhancement is only with an Al/LiF (0.6 nm) cathode but not with a silver (Ag)/LiF (0.6 nm) [11]. Another study by Wang et al., however, opposed the result and showed that a Ag/LiF (3.0 nm) cathode can also increase the electron injection by varying the LiF thicknesses [12]. The significances of two studies are that they are each supporting differently one of the two categorized models.

2. Experiments

Here, we have conducted an experiment to classify the role of LiF inside an OLED. Our control device (CD) has the configuration of Al (100.0 nm)/Alq_3 (50.0 nm)/alpha-*N*,*N*′-bis(naphthalene-1-yl)-*N*,*N*′-bis(phenyl)benzidine (α-NPB) (50.0 nm)/indium tin oxide (ITO) (70.0 nm), which does not have a LiF EIL at the Al/Alq_3 interface on purpose. The 0.3 nm thin LiF layer has been inserted inside an Alq_3 ETL. Inserting LiF at one forth, half or three forth position inside Alq_3 of CD gives our device configurations of Al (100.0 nm)/Alq_3 (12.5 nm)/LiF (0.3 nm)/Alq_3 (37.5 nm)/NPB (50.0 nm)/ITO (70.0 nm), Al (100.0 nm)/Alq_3 (25.0 nm)/LiF (0.3 nm)/Alq_3 (25.0 nm)/NPB (50.0 nm)/ITO (70.0 nm), and Al (100.0 nm)/Alq_3 (37.5 nm)/LiF (0.3 nm)/Alq_3 (12.5 nm)/NPB (50.0 nm)/ITO (70.0 nm). Other devices substituting the ETL part of Alq_3 by copper phthalocyanine (CuPc) has also been prepared. The Fig. 1 depicts CD and each configuration of our devices.

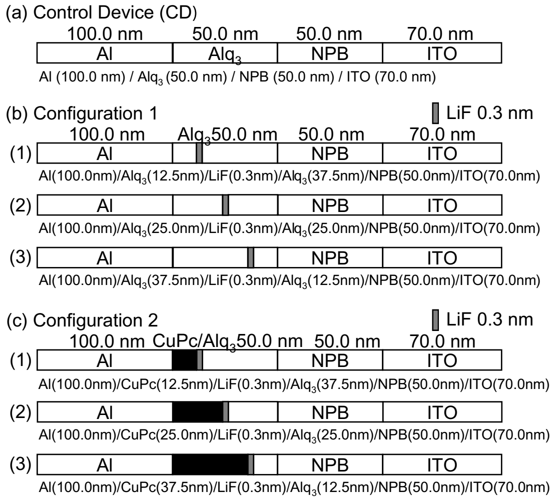

Fig. 1. The control device (CD) and two different configurations of organic light-emitting devices in the experiment. (a) The first configuration is characterized as thin (0.3 nm) LiF layers at one forth, half or three forth position of Alq_3 inside CD. (b) The second configuration has a CuPc electron transport layer (ETL) substitution of the first configuration.